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To: Instrumentation Laboratory Personnel

From: D. G. Hoag

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Subject: Report on Apollo 11

While the fascinated world watched by television, on July 20, 21 two American astronauts walked the "magnificent desolation" of the moon's Sea of Tranquility. Apollo's eight-year goal has suddenly passed into history with deceptive ease.

The guidance, navigation, and control systems of Apollo 11 in each vehicle again operated without failure, but an unexpected arrangement of rendezvous radar mode switches put a heavy burden on the LM computer during powered lunar descent. With low voltage and wrong phase at the radar gimbal angle interface, the computer was forced to count high frequency pulses which consumed a large portion of the machine's computation capacity. Five times during the landing the computer displayed alarms indicating that overload had caused "restart" and meaning necessarily that service to low priority tasks was temporarily suspended. (We will provide computer program interlocks in future flights to prevent the overload conditions arising from this situation.) The computer was not confused; it successfully continued the vital landing computations and control functions for an automatic landing. MIT had carefully briefed the crew and mission controllers on the meaning of the alarm and specifically on the more benign nature of the ones which occurred. It was to the credit of Armstrong and the ground controllers, who with remarkable calm believed that no more than the indicated trouble was present and allowed the automatic landing to proceed.

At 410 feet altitude Armstrong switched the computer to a semiautomatic mode, program P66, so that he could maneuver away from a rock-strewn young ray crater at the programmed landing point. Tranquility Base was established about 500 feet west of this crater and only 3.5 nautical miles west of the nominal landing target. This small miss was due largely to the initial conditions given the onboard system which were corrected for the gravity anomolies that were discovered in earlier missions to perturb ground based radar tracking navigation and extrapolation of lunar orbits.

The onboard indicated location of the landing point was measured using first star and lunar gravity tracking of program P57 and then rendezvous radar tracking of the command module of program P20. The former differed by

2.5 nautical miles and the latter differed by 0.2 nautical miles from the landing point inferred from observation of landmarks seen on the sequence film taken through the window during the landing. The many sources of indicated landing coordinates all agreed close enough to assure by a wide margin safe liftoff and rendezvous. Accuracy was desired to help Collins in using Program P22 to find the LM optically on the lunar surface through the sextant. From orbit the optical field of view was only about 0.5 nautical miles on the moon's surface. The problem was made more difficult by the orbital motion of the CM and the very small size of the image of the LM and its shadow. It was a disappointment that the attempt had to be terminated after several tries due to the reaction control fuel that was being consumed.

The countdown and liftoff from the moon was smooth. Rendezvous proceeded without difficulty following the profile exercised on the earlier Apollo 10 flight. In the LM, Armstrong and Aldrin used the rendezvous radar and inertial system for the rendezvous calculations, while independently in the CM, Collins was generating corresponding solutions in his computer with his optics and VHF ranging measurements. In every phase both sets of solutions converged to near identical answers and close to those generated from the ground radar tracking. The LM made the maneuvers based upon the onboard measurements and computations.

The return to earth was without problems. Following the pattern of the two earlier missions, only one small midcourse correction was made. Due to inclement weather in the original recovery area the entry range was increased 215 nautical miles to a new landing point. This was done by putting the new target into the computer which then modified the original atmospheric entry profile to include the up-control phase of program P65 to extend the range. The recovery ship was some 12 nautical miles NE of the new target at the time of splashdown. The control system steered the command module to an onboard indicated error of about 1.5 nautical miles at the time of drogue chute deployment.

The astronauts of Apollo 11 brought back 54 pounds of the moon and left footprints on the dusty soil. But this is only a small part of what has been achieved. We at MIT can take pride in what has been demonstrated possible in complex measurement and control equipment. Our system hardware design has supported over 850 hours of operational space flight with outstanding performance and without failure. Our software has executed the most intricate of interacting operations to support this historic mission. These unparalleled achievements were accomplished only through the competence, ingenuity, dedication, and toil of MIT employees and support contractors. Many started the program with little experience, but now are seasoned and proficient engineers, programmers, and technicians. Many whose special inspired contribution made success possible deserve special commendation.

Nine more lunar landings are planned, the next now scheduled in November. These are intended to visit areas of more scientific interest and have more stringent guidance, navigation, and control requirements. MIT will continue to supply the quality engineering design and support for these landings as well as for other interesting programs.

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